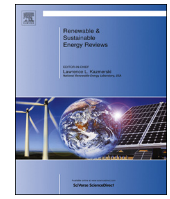
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Review of software tools for hybrid renewable energy systems

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A R T I C L E I N F O

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A B S T R A C T

Hybrid energy systems are being utilized for supplying electrical energy in urban, rural and remote areas to overcome the intermittence of solar and wind resources. A hybrid renewable energy system incorporates two or more electricity generation options based on renewable energy or fossil fuel unit. The techno-economic analysis of the hybrid system is essential for the efficient utilization of renewable energy resources. Due to multiple generation systems, hybrid system analysis, is quite complex and requires to be analyzed thoroughly. This requires software tools for the design, analysis, optimization, and economic viability of the systems. In this paper, 19 softwares with their main features and current status are presented. The softwares studied are HOMER, Hybrid2, RETScreen, iHOGA, INSEL, TRNSYS, iGRHYSO, HYBRIDS, RAPSIM, SOMES, SOLSTOR, HySim, HybSim, IPSYS, HySys, Dymola/Modelica, ARES, SOLSIM, and HYBRID DESIGNER. The research work related to hybrid systems carried out using these softwares at different locations worldwide is also reviewed. The main objective of the paper is to provide the current status of these softwares to provide basic insight for a researcher to identify and utilize suitable tool for research and development studies of hybrid systems. The capabilities of different softwares are also highlighted. The limitations, availability and areas of further research have also been identified.

Contents

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1. Introduction

Energy demand is increasing day by day due to increase in population, urbanization and rapid industrialization. This makes direct connection between energy use and quality of life. The fossil fuel resources, like coal, oil and gas, have limited reserves which results in continued fuel price hike which affects the economy of any country. Due to oil crisis of 1970s, considerable interest has resulted in utilizing renewable energy sources. Renewable energy is obtained from sun, wind, biomass, water, tides, ocean waves and geothermal heat.

Renewable energy systems are based on single source or multiple sources of renewable generators. Single source based renewable energy system incorporates only one electricity generation option based on wind/solar thermal/solar photovoltaic (PV)/hydro/biomass etc. along with appropriate energy storage and electronic systems. A hybrid energy system incorporates two or more electricity generation options based either on renewable energy unit or fossil fuel based unit like diesel–electric generator or a small gas-turbine along with energy storage and electronic devices. Several hybrid energy system configurations can be used for power generation like PV–wind–diesel systems, hydro–wind–PV-based systems, biomass–wind–PV installations, wind–PV based installation, PV–wind–hydrogen/fuel cell hybrid energy systems etc. Hybrid energy system has following main advantages in comparison to single source based system:

- Higher reliability
- Reduced energy storage capacity especially where different sources have complementary behavior.
- Better efficiency.
- Minimum levelized life-cycle electricity generation cost, when optimum design technique is used.

But in most cases due to lack of optimum designing or proper sizing, a hybrid energy system, is over-sized or not properly planned or designed, which makes installation cost high. The technical and economical analyses of a hybrid system are essential for the efficient utilization of renewable energy resources. Due to multiple generation systems, hybrid system solution is complex and requires to be analyzed thoroughly. This requires software tools and models which can be used for the design, analysis, optimization and economical planning. A number of softwares have been developed to assess the technical and economical potential of various hybrid renewable technologies to simplify the hybrid system design process and maximize the use of the renewable resources. In the study hybrid system analysis softwares are reviewed. The main objective of the paper is to provide a basic insight to a researcher to identify and utilize suitable software tool effectively, as per the requirements for research and development studies related to hybrid systems. In this study, applications and status of 19 softwares namely HOMER, Hybrid2, RETScreen, iHOGA, INSEL, TRNSYS, iGRHYSO, HYBRIDS, RAPSIM, SOMES, SOLSTOR, HySim, HybSim, IPSYS, HySys, Dymola/Modelica, ARES, SOLSIM, and Hybrid Designer are presented. A comparative analysis of these softwares along with literature review of research carried out using these softwares worldwide, are presented. The limitations, availability and areas of further research have also been identified. The analysis of a PV–battery and PV–wind–battery hybrid system is presented as case studies using HOMER and RETScreen.

The paper is organized as follows: Section 2 provides an overview of various software tools with their main features, Section 3 gives a literature survey of hybrid energy systems using some of the software tools, Section 4 deals with the case studies and conclusion is given in Section 5.

2. Software tools for hybrid system analysis

A comprehensive understanding is essential about available hybrid system models and software tools, their features, shortcomings, user need and choice for research studies. In this section, the main features of 19 softwares developed for hybrid system design are discussed along with a comparative analysis.

Turcotte et al. [1] classified the software tools related to hybrid systems in four categories: pre-feasibility, sizing, simulation and open architecture research tools. The prefeasibility tools are mainly used for rough sizing and a comprehensive financial analysis(e.g. RETScreen). The sizing tools are used for the determination of optimal size of each component of the system and provide detailed information about energy flows among various components (e.g. HOMER). In a simulation tool, the user has to specify the details of each component in order to get the detailed behavior of the system (e.g. HYBRID 2). In open architecture research tool, user is allowed to modify the algorithms and interactions of the individual components (e.g. TRNSYS). Klise and Stein [2] described various PV performance models, hybrid system performance models and battery storage models in a Sandia National Laboratory report. Arribas et al. [3] carried out a survey of ten existing software tools based on the availability, features and applications and presented guidelines and recommendations in a International Energy Agency (IEA) report. This report also categorized tools into four categories namely dimensioning, simulation, research and mini-grid design tools. Connolly et al. [4] surveyed 37 computer tools for analyzing integration of energy systems. The survey also includes three hybrid simulation tools HOMER, RETScreen and TRNSYS. The survey was carried out in collaboration with tool developers which included five components namely background information, users, tool properties,

application, case studies and further information. This study provides information for analyzing the integration of renewable energy into different objective based energy-systems.

Ibrahim et al. [5] briefly described, the design and simulation models of the hybrid systems working with wind–diesel hybrid systems for remote area electrification. Bernal-Agustin and Dufo-LóPez [6] revises the simulation and optimization techniques, as well as the existing tools used for stand-alone hybrid system design. Zhou et al. [7] have described HOMER, HYBRID 2, HOGA and HYBRIDS which are used for evaluating performance of the hybrid solar–wind systems. Erdinc and Uzunoglu [8] discussed about the commercially available software tools for hybrid system sizing simulation.

However, no comprehensive review of the hybrid software tools discussed in the present study till date has been found in the literature. In order, to provide a basic insight to utilize these tools in various research studies effectively the identified nineteen softwares with focus on hybrid systems with renewable energy component, are discussed as follows:

2.1. HOMER

The Hybrid Optimization Model for Electric Renewables (HOMER), is most widely used, freely available and user friendly software. The software is suitable for carrying out quick prefeasibility, optimization and sensitivity analysis in several possible system configurations. The National Renewable Energy Laboratory (NREL) USA has developed HOMER for both on-grid and off-grid systems in 1993 and from the date of release, HOMER has been downloaded by over 80,000 people in 193 countries [9]. HOMER uses windows as computer platform with visual C++ as programming language. HDKR (Hay, Davies, Klucher, and Reindl) anisotropic model for solar photovoltaic system is used by this software. HOMER uses inputs like various technology options, component costs, resource availability, manufacturer's data etc. to simulate different system configurations and generates results as a list of feasible configurations sorted by net present cost. This software can simulate a system for 8760 h in a year. HOMER also displays simulation results in a wide variety of tables and graphs which helps to compare configurations and evaluate them on their economic and technical merits. It can determine load serve policies with lowest cost source to meet the load. HOMER can suggest the design of various systems based on economic parameters. The tables and graphs made by HOMER simulation can also be exported. HOMER has been used extensively in literature for hybrid renewable energy system optimization and various case studies. Fig. 1 gives a schematic representation of HOMER. The last updated version of HOMER is 2.81 (Nov2010). The main limitations of Homer are as follows:

- HOMER allows only single objective function for minimizing the Net Present Cost (NPC) as such the multi-objective problems cannot be formulated. After optimization process HOMER makes chart for the optimized system configurations based on NPC and does not rank the hybrid systems as per levelized cost of energy.
- HOMER does not consider depth of discharge (DOD) of battery bank which plays an important role in the optimization of hybrid system, as both life and size of battery bank decreases with the increase in DOD. Therefore, the DOD should either be optimized or be included in sensitivity inputs of the Homer.
- HOMER does not consider intra-hour variability.
- HOMER does not consider variations in bus voltage.

Including flexibility in selecting optimization technique relevant to a particular study in HOMER will enhance its robustness and will facilitate the comparative study of results using different techniques [10].

2.2. HYBRID 2

HYBRID 2 is developed by Renewable Energy Research Laboratory (RERL) of the University of Massachusetts, USA with support from National Renewable Energy Laboratory [11]. After Hybrid1 in 1994, Hybrid2 was developed in 1996 and now the most recent version is 1.3b, which can be downloaded and installed with a password on Windows XP version. Some changes have been made in the latest version of HYBRID 2 and problems like curve fitting function on the insolation data graph, overflow error with low load simulation etc have been fixed. This software is programmed in Microsoft Visual BASIC and uses a Microsoft Access Database. HYBRID 2 is a probabilistic/time series computer model and uses statistical methods to account for inter time step variations and can perform detailed long term performance, economic analysis and predict the performance of various hybrid systems. HYBRID 2 has a provision of time series simulations for time steps typically between 10 min and 1 h. HYBRID 2 allows systems based on three buses containing wind turbines, PV array, diesel, battery storage, power converters and a dump load. HYBRID 2 mainly contains four parts namely the Graphical User Interface (GUI), the Simulation Module, the Economics Module and the Graphical Results Interface (GRI). Using GUI the user can construct projects easily and maintain an organized structure. The Simulation and Economics Modules allow the user to run simulations and input error checking. Users can view details graphical output data though GRI. Fig. 2 gives a schematic diagram of of HYBRID2. This software tool has a limited access to parameters and lack of flexibility but it has a library with various resource data files. A password is needed to install the demo version of HYBRID 2 [12–13].

2.3. RETScreen

RETScreen is feasibility study tool and is freely downloadable software developed by Ministry of Natural Resources, Canada [14] for evaluating both financial and environmental costs and benefits of different renewable energy technologies for any location in the world. This software uses visual basic and C language as working platform. Fig. 3 gives a schematic representation of RETScreen software. RETScreen was released in 1998 for on-grid applications. RETScreen PV model also covers off-grid PV applications

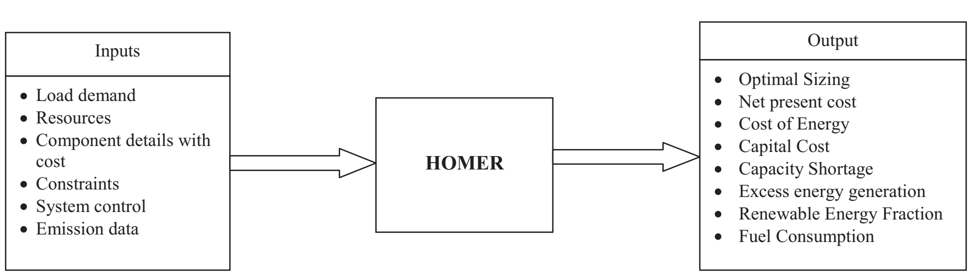


Fig. 1. Schematic representation of HOMER.

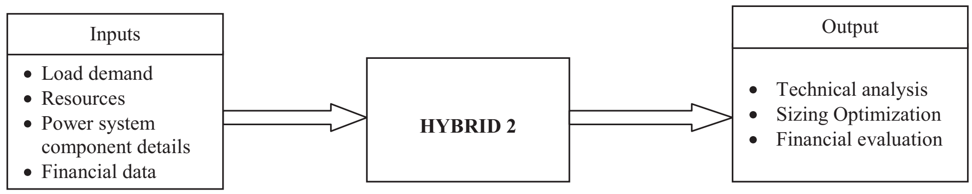


Fig. 2. Schematic representation of Hybrid 2.

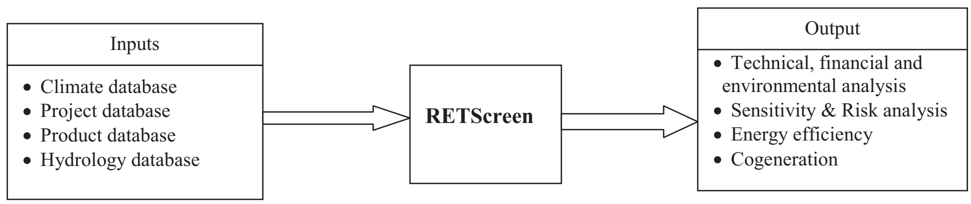


Fig. 3. Schematic representation of RETScreen.

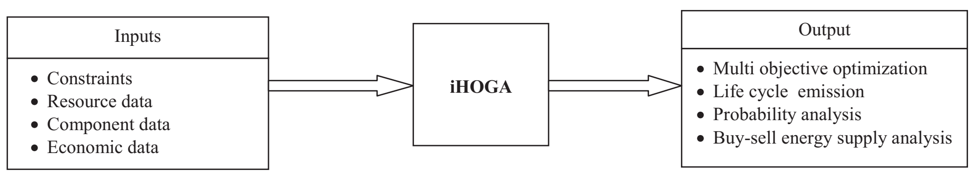


Fig. 4. Schematic representation of iHOGA.

and include stand-alone, hybrid and water pumping systems also. It has a global climate data database of more than 6000 ground stations (month wise solar irradiation and temperature data for the year), energy resource maps (i.e. wind maps), hydrology data, product data like solar photovoltaic panel details and wind turbine power curves. It also provides link to NASA climate database. The program is accessible in more than 30 languages and has two separate versions, RETScreen 4 and RETScreen Plus. RETScreen 4, is a Microsoft excel based energy project analysis software tool which can determine the technical and financial viability of renewable energy, energy efficiency and cogeneration projects. There are a number of worksheets for performing detailed project analysis including Energy Modeling, Cost Analysis, Emission Analysis, Financial Analysis and Sensitivity and Risk Analyses sheets. RETScreen is used for the analysis of different types of energy efficient and renewable technologies (RETS) covering mainly energy production, life-cycle costs and greenhouse gas emission reduction.

RETScreen Plus is a Windows-based energy management software tool to study the energy performance. This program requires Microsoft Excel 2000,Microsoft Windows 2000 and Microsoft.NET Framework 2.0 or higher versions and it is also possible to work on Apple Macintosh computers using Virtual Box for Mac. The main limitations of RETScreen are:

- Does not take into account effect of temperature for PV performance analysis.
- No option for time series data file Import.
- Limited options for search, retrieval and visualization features.
- Data sharing problem.
- Does not support more advanced calculations.

2.4. iHOGA

Improved Hybrid Optimization by Genetic Algorithm (**iHOGA**) formerly known as HOGA (Hybrid Optimization by Genetic Algorithm) is a C++ based hybrid system optimization software tool developed by the University of Zaragoza, Spain [15–16]. iHOGA is used for optimum sizing of hybrid energy system which may include photovoltaic system, wind turbines, hydroelectric turbines, fuel cells, H_2 tanks, and electrolyzers,storage systems, fossil fuel based generating systems etc. with multi or mono objective optimization using Genetic algorithm and sensitivity analysis with a low computational time. iHOGA can optimize the slope of the PV panels, calculates life cycle emissions, and allows probability analysis and has purchase and selling energy options to the electrical grid with net metering system. Fig. 4 gives a general schematic representation of iHOGA. The new iHOGA version is upgraded and includes degradation effects, sensitivity analysis, new constraints, database of various components, currency changing facility etc. It has two versions namely PRO+ and EDU. PRO+ is a priced version which can be used without any limitation with all features and full technical support, whereas EDU version which free can be used for training or educational purposes only and is not permitted in projects, engineering work, installation work and for any work involving economic transactions. The limitations of EDU version are as follows:

- It can only simulate within a total average daily load of 10 kWh.
- Sensitivity analysis is not included.
- Probability analysis is not included.
- Net metering is not included.

The latest version of iHOGA is 2.2 (November 2013) and can run only in Windows XP, Vista, 7 or 8. All versions of iHOGA need internet connection to get the validity of license, otherwise it will not run.

2.5. INSEL

A general-purpose graphical modeling language INSEL (Integrated Simulation Environment Language) was developed by University of Oldenburg, Germany which allows the users to make a structure with the help of its library with a specified execution

time [17]. This simulation software has the flexibility of creating system models and configurations for planning and monitoring of electrical and thermal energy systems. This software has its own database of meteorological parameters of almost 2000 locations worldwide, photovoltaic systems, thermal systems and other devices hourly irradiance, temperature, humidity and wind speed data can be generated by using this software from monthly mean values for any given location and orientation. Solar thermal systems also can simulate using INSEL. The software is under continuous improvement during the last 2 decades.

2.6. TRNSYS

In 1975 University of Wisconsin and University of Colorado (USA) jointly developed energy system simulation software named Transient Energy System Simulation Program (TRNSYS) [18]. TRNSYS was initially developed for thermal systems simulation, but with a span of more than 35 years, this software has upgraded and changed it features. It has now included photovoltaic, thermal solar and other systems and has become a hybrid simulator. This simulation program is developed for modeling of thermal energy flows based on FORTRAN code. This is extremely flexible graphically based software used to simulate transient system behavior with two parts one is kernel and another is library. Kernel processes the input file and solves the system with various techniques and determines convergence whereas, the second part library includes various models which can also modified by user. TRNSYS does not provide optimization facilities but it carries out simulation with great precision with graphics and other details. TRNSYS is used in solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells etc. Fig. 5 shows a general schematic representation of TRNSYS architecture. The latest version of TRNSYS is 17.1 released on June 2012 and is priced.

2.7. iGRHYSO

iGRHYSO (improved Grid-connected Renewable HYbrid Systems Optimization) [19] is the improved version of the GRHYSO, which is developed in C^{++} for grid connected hybrid renewable energy systems optimization.This software is available only in Spanish language. iGRHYSO simulates and optimizes various renewable energy systems like photovoltaic, wind, small hydro etc with storage batteries using different technologies or hydrogen. The NASA website [20] is connected with this software which is helpful for importing irradiation, wind, and temperature data. The effects of temperature on photovoltaic generation and production by wind turbines can also be studied by using this software. This tool also considers different types of sales/purchase of electricity from grid. The IRR (Internal Rate of Return) can be calculated. This software can export simulation data in excel spreadsheet format.

2.8. HYBRIDS

HYBRIDS is a Microsoft Excel spreadsheet-based and commercially available renewable energy system assessment application and design tool produced by Solaris Homes. It requires daily-average load and environmental data estimated for each month of the year. It can only simulateone configuration at a time, and is not designed to provide an optimized configuration. The user can improve design skills about renewable energy system using HYBRIDS.

2.9. RAPSIM

In 1996 University Energy Research Institute (MUERI), Australia, developed Remote Area Power SIMulator or RAPSIM which is a Windows based software package for hybrid system model. The software can simulate the performance of a range of hybrid power systems comprising of PV arrays, wind turbines and diesel generators with battery storage. Solar radiation, wind speed, ambient temperature, system load etc. are the main inputs required by RAPSIM. In 1997 version 2 of this software was available but whether updates after year 1997 have been made to the software or not, is not clear [21].

2.10. SOMES

Simulation and Optimization Model for Renewable Energy Systems (SOMES) developed in 1987 at Utrecht University, Netherlands. This model can simulate hourly basis with an average electricity production from the renewable energy generators. The model can perform optimization task for searching lowest electricity costs within defined constraints. This model uses inputs like weather data, load demand etc to get technical and economical performance of a particular system configuration [22].

2.11. SOLSTOR

Sandia National Laboratory (SNL) developed a model in late 1970s and early 1980s to carry out economics and optimization analysis for various Hybrid systems [23] known as SOLSTOR. This model includes renewable energy components like PV arrays, wind turbines etc., storage batteries and other power conditioning options and utility grid or fuel burning generator can be also used as backup electricity provider. This software can minimize the life cycle cost of energy by choosing the optimal solar or wind system component size. SOLSTOR can also find rates for electricity purchased from the grid, time-of-day (TOD) energy charges as well as time-of-day peak demand changes and sell back to the grid of excess collected energy. The model can be run with on grid and off grid condition both. But now this model is no longer used and updated.

2.12. HySim

HySim is a hybrid energy simulation model developed by Sandia National Laboratory [2] in 1987 for analyzing remote rural off grid hybrid system with PV, diesel generators and battery storage combination with good system reliability. HySim carries out financial analysis including Life Cycle, fuel, Levelized Cost of Energy, and operation and maintenance costs, and cost comparisons between different configurations. HySim has not been used after 1996.

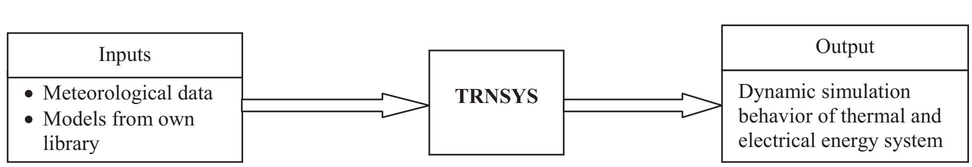


Fig. 5. Schematic representation of TRNSYS.

2.13. HybSim

HybSim developed Sandia National laboratory, is a hybrid energy software for cost benefit analysis of remotely located hybrid system comprising of fossil fueled electrical generation source with renewable source [24]. This tool requires detailed load profile, battery characteristics, economic details of whole system and weather characteristics. HybSim can use data measured at 15 min intervals. Cost comparison and performance comparison of various system component combinations can be evaluated through this software. HybSim version 1 (2005) is available and is undergoing development.

2.14. IPSYS

Integrated Power System tool known as IPSYS is a hybrid simulation modeling tool for remote systems with a component library and able to make simulation of electricity generation through PV arrays, wind turbines, diesel generators, energy storage batteries hydro-reservoirs, fuel cells as well as natural gas. C++ language is used for this model and no current graphical user interface option is available but some scripts can be used to analyze graphical output [25–26].

2.15. HySys

The Hybrid Power System Balance Analyser, also known as HySys is a hybrid simulation tool developed by wind technology group, Centro de Investigaciones Energeticas, Medioambientalesy Technologicas (CIEMAT) Institute in Spain for sizing and long-term analysis of off grid hybrid systems mainly comprising with PV arrays, wind turbines and diesel generators and it can operate within Matlab. In 2003 version 1.0 of this software was developed but now it is currently being used internally by CIEMAT only [27].

2.16. Dymola/Modelica

Dymola/Modelica is used by the Fraunhofer Institute for Solar Energy (ISE) in Germany for modeling hybrid systems along with PV, wind turbines, generators, fuel cells and storage batteries with weather and insolation data inputs. It can evaluate lifecycle costs and calculate levelised cost of energy but now update status of this software is unknown [23].

2.17. ARES

Autonomous Renewable Energy Systems (ARES) is a program developed at the Cardiff school of engineering, University of Wales, UK for simulation of PV–wind–battery systems. This software is able to calculate the system loss of load probability and system autonomy through the prediction of the storage battery voltage if input load and basic weather profile is given. The software has two versions ARES-I and modified version of ARES-I by Morgan et al. [28] is known as ARES-II. ARES-I, consisted of subroutine program in the following order: (1) weather statistics, (2) photovoltaic generation, (3) wind generation, (4) load calculation, (5) combined source and load current, (6) battery voltage subroutine, (7) controller action, and (8) presentation of results. ARES-II required load and basic weather profile inputs and calculates the system loss of load probability and system autonomy using storage battery voltage prediction. This software is not available now.

2.18. SOLSIM

Fachhochschule Konstanz (Germany) developed a technically sophisticated and flexible tool named SOLSIM [5] for hybrid renewable simulation using photovoltaic panels, wind turbines, diesel generators, batteries and bio-energy systems for electricity and heat generation. This software can carry out an economic analysis with very limited control options (e.g. photovoltaic panel tilt angles). SOLSIM allows large amount of very specific data to enter for simulation adjustment. The large amount of data created from each simulation can be displayed in either hourly, daily, weekly or monthly intervals including graphic user interface as a feature which makes the program easy to learn and to use [29]. This software is not available.

2.19. Hybrid Designer

Hybrid Designer [29] was developed by the Energy and Development Research Centre (EDRC) of the University of Cape Town in South Africa and was funded by the South African Department of Minerals & Energy. This tool is mainly used for off grid applications in Africa′s weather condition. It is user friendly software based on genetic algorithm which can evaluate different configurations with minimum lifecycle cost. Hybrid Designer can simulate different sources such as photovoltaics, wind generator, battery and an engine generator and produces a complete solution with technical aspects and life cycle costs.

The highlights including latest version available, work platform and type of analysis of the 19 hybrid simulation softwares are shown in Table 1

The comparative features of these software tools based on technical and economical analysis capabilities and renewable energy generator options are shown in Table 2.

A comparative analysis of freely accessible and most used softwares for hybrid system research is given in Table 3

3. Research studies using hybrid system software tools

The hybrid system analysis software tools have been used by a number of researchers worldwide. HOMER is found to be most widely used tool in the research studies followed by RETSCREEN, HOGA, HYBRID2, TRNSYS and ARES.

3.1. HOMER based studies

In this section some hybrid system analysis studies using HOMER, for various locations are discussed to highlight the usefulness of HOMER.

Sopian et al. [30] investigated the optimization calculations by HOMER and genetic algorithm both and found almost same results and time taken to execute the program. Al-Karaghouli and Kazmerski [31] used HOMER, to estimate the system size and its lifecycle cost of a total daily 31.6 kW load of health clinic in southern Iraq and suggested most economic system consists of 6-kW PV modules, 80 batteries (225 Ah and 6 V), and a 3-kW inverter. Authors also suggested that, this type of system is good for remote rural electrification as electricity produced from diesel generator, is four times costlier than PV electricity and also prevents release of CO_2, CO, NO_x, hydrocarbons, SO_2, and suspended particles. Rehman and Al-Hadhrami [32] carried out the technical and economical analysis for a small village of Saudi Arabia with a PV–diesel–battery hybrid system which provides a cost reduction, air pollutant minimization to the atmosphere, reduce the diesel consumption and maintain a continuous supply of power as compared to only diesel system. Fulzele and Dutt [33]

Table 1
Main highlights of various software tools for hybrid systems.

Softwares	Developed by	Latest version	Computer platform	Analysis type	Availability
HOMER	NREL,USA (1993)	HOMER 2 Version 2.81 (Nov, 2010)	Windows Visual C++	Technical analysis; economical analysis; emission analysis	Free www.homerenergy.com
HYBRID2	University of Massachusetts, USA and NREL (Hybrid1 in 1994, Hybrid 2 in 1996)	Version 1.3	Windows XP Visual BASIC	Technical analysis; economical analysis	Free http://www.ceere.org/rerl/rerl_hybridpower.html
RETScreen	Developed by Ministry of Natural Resources, Canada in 1998	RETScreen 4 and RETScreen Plus	Windows 2000, XP, Vista Excel, Visual Basic, C	Financial, environmental analysis	Free http://www.retscreen.net/
iHOGA	University of Zaragoza, Spain	Version 2.2 (Nov, 2013)	Windows XP, Vista,7 or 8C++	Multi or mono objective optimization using genetic algorithm	PRO version is priced & EDU version is free, http://www.unizar.es/rdufo/hoga-eng.htm
INSEL	German University of Oldenburg (1986–1991)	–	Windows Fortran and C/C++	Planning, monitoring of electrical and thermal energy systems	Priced www.insel.eu
TRNSYS	University of Wisconsin and University of Colorado (1975)	Version 17.1	Windows Fortran code	Simulate transient system behavior	Priced http://www.trnsys.com/
iGRHYSO	University of Zaragoza, Spain	_	Windows C++	Technical analysis; economical analysis	Priced http://www.unizar.es/rdufo/grhyso.htm
HYBRIDS	Solaris Homes	_	Windows spreadsheet based software	Technical analysis	Unknown
RAPSIM	University Energy Research Institute Australia(1996)	Version 2 (1997)	Windows	Simulates performance of a range of hybrid power systems	Unknown, after 1997 any modifications are not reported
SOMES	Utrecht University, Netherlands (1987)	–	Windows Turbo pascal	Technical analysis; economical analysis	Unknown http://www.uu.nl/EN/Pages/default.aspx
SOLSTOR	SNL (late 1970s and early 1980s)	–	Windows Fortran	Technical Analysis	Not used now http://www.sandia.gov/
HySim	SNL (late 1980s)	–	–	Financial analysis	After mid 1990s this model is not used
HybSim	SNL	–	–	Cost benefit analysis	Unknown
IPSYS	–	–	Windows, Linux	Modeling; simulation with control strategies	Unknown www.risoe.dtu.dk
HYSYS	Wind technology group(CIEMAT), Spain	Version 1.0 (2003)	–	Sizing; long-term analysis of off grid hybrid systems	Unknown
Dymola/modelica	Fraunhofer Institute for solar energy, Germany	–	Windows C++	Modeling hybrid systems; financial evaluation	Unknown
ARES	Cardiff school of engineering, University of Wales, UK	–	Windows	Technical analysis; economical analysis	Not available
SOLSIM	Fachhochschule Konstanz (Germany)	–	Windows	Technical analysis; economical analysis	Not available
Hybrid Designer	Energy and Development Research Centre (EDRC), University of Cape Town, SA	–	Windows	Technical analysis; economical analysis	Unknown

Table 2
Analysis capabilities of hybrid system software tools.

Tools	Economical Analysis	Technical Analysis	PV System	Wind System	Generator set	Storage device	Bio-energy	Hydro energy	Thermal System
HOMER	X	X	X	X	X	X	X	X	-
HYBRID2	–	X	X	X	X	X	–	–	X
iHOGA	X	X	X	X	X	X	–	X	–
RETScreen	X	X	X	X	–	X	–	–	–
HYBRIDS	–	X	X	–	–	X	–	–	–
SOMES	X	X	X	X	–	X	–	–	–
RAPSIM	–	X	X	X	X	X	–	–	–
SOLSIM	X	X	X	X	X	X	X	–	–
ARES-I &II	–	X	X	X	X	X	–	–	–
HYSYS	–	X	X	X	X	X	–	–	–
INSEL	–	X	X	X	X	X	–	–	X
SOLSIM	X	X	X	X	X	X	X	–	–
HybSim	X	X	X	–	X	X	–	–	–
Dymola/Modelica	X	–	X	X		X			
SOLSTOR	X	X	X	X	X	–	–	–	–
HySim	X	X	X	–	X	X	–	–	–
IPSYS	–	X	X	X	X	X	–	X	–
Hybrid Designer	X	–	X	X	X	X	–	–	–
TRNSYS	X	X	X	X	X	X	–	–	X
iGRHYSO	X	X	X	X	–	X	–	X	–

Table 3
Comparative analysis of freely accessible softwares.

Softwares	Advantages	Disadvantages
HOMER	• User friendly • easy to understand • provides efficient graphical representation of results • hourly data handling capacity	• "Black Box" code used • first degree linear equations based models used • time series data in a form of daily average can't be imported
RETScreen	• Strong product database and meteorological database from NASA only • financial analysis is the main strength • easy to use as it is EXCEL based software.	• No time series data import options • less data input options • limited options for search, retrieval and visualization features
HYBRID 2	• User friendly • multiple electrical load options • detailed dispatching option	• Does not work on Windows platforms later than Windows XP • some simulation errors shown although project is written successfully
HOGA	• Use multi or mono objective optimization using Genetic Algorithm and sensitivity analysis • required low computational time. • purchase and selling energy options to the electrical grid with net metering system available.	• Free EDU version has some limitations in analysis • internet connection is required to activate license

used HOMER for optimum planning of a proposed hybrid system based on mathematical modeling of each component for site located in Dudhagaon village in Maharastra, India and showed that solar PV generator with battery and inverter is the most economical solution over PV–wind with battery. This paper also concluded that although different renewable energy systems are technically suitable and available in market but all are not financially viable.

Nema et al. [34] studied PV–solar and wind hybrid energy system for GSM/CDMA type mobile base station in Bhopal – Central India, which is suitably modeled using HOMER software. Sureshkumar et al. [35] presented real time optimal cost analysis of hybrid system based on the load profile, solar radiation and wind speed for a location Mandapam in Tamil Nadu, India and optimized the system based upon the total net present cost. Akella et al. [36] developed an Integrated Renewable Energy System (IRES) model consisting of mini-hydel power, solar photovoltaic, wind energy system and biomass energy system had been optimized using LINDO (Linear, Interactive, and Discrete Optimizer) software 6.10 version. The results were verified using TORA software version 1.00 and also comparative results were also shown between LINDO as well as HOMER software. Kumaravel and Ashok [37] carried out the size optimization of a hybrid energy system for remote area electrification in Kakkavayal, Kerala, India, and analyzed the economical feasibility using solar PV/biomass/pico-hydel hybrid energy system and found that a biomass gasifier hybrid energy system is more suitable for rural areas of Western Ghats region of India. Afzal et al. [38] carried out the sizing, sensitivity, optimization, and greenhouse gas emission analyses of a hybrid renewable energy systems for two locations namely Lakshadwip and Uttarpradesh with same load demand and identified different configurations. Sinha and Chandel [39] carried out prefeasibility study to assess the potential for solar-wind hybrid systems for Hamirpur in the Western Himalayan state of Himachal Pradesh, India using one year time series solar and wind data. The analysis shows that, Hamirpur has an excellent solar resource but low wind potential as such solar PV–micro-wind–battery storage system will be suitable for residential and institutional buildings to this location.

Prasad [40] used HOMER software to determine the optimum hybrid configuration and the levelised cost of energy for Vadravadra site in Fiji Island. A pre-feasibility study of hybrid energy systems with hydrogen storage is done by Khan and Iqbal [41] with various energy options like wind, solar, diesel generator, battery storage systems, and electrolyzer–tank for applications in Newfoundland. The results show the suitability of a wind–diesel–battery system for stand-alone applications as wind resources in Newfoundland has excellent potential. Zoulias and Lymberopoulos [42] studied the feasibility of replacement of fossil fuel based generator with hydrogen technologies and found it technically feasible but not economically viable due to higher cost of hydrogen technologies. Himri et al. [43] presented an economical feasibility study of an existing grid-connected diesel power plant by adding wind turbine to reduce the diesel consumption and environmental pollution, and concluded that the wind–diesel hybrid system becomes feasible at a wind speed of 5.48 m/s or more and a fuel price of 0.162 $/l or more.

Liu et al. [44] carried out the modeling and sensitivity analysis of wind–solar hybrid system for Yantai city, China and obtained optimal results which helped in future micro grid planning. The technical and financial viability of a large-scale grid-connected hotel (over 100 beds) using real load data has been presented by Dalton et al. [45] and carried out the analysis, and viability on the basis of net present cost, renewable fraction and payback time. The results indicate that wind energy system is more economically viable technology for large-scale grid-connected operations in this case. Dursun et al. [46] have shown, that how a PV/wind/diesel–battery system consisting of 4 wind turbines, a 125 kW diesel generator, 96 batteries, a 100 kW converter, and a 120 kW PV array can minimize the dependence on fossil fuel source to meet 124 kWh load which leads to decrease in total Net Present Cost and Cost Of Energy and the amount of pollutants emitted and creates a green house effect free environment.

Badi et al.[47] designed a model to assess wind and solar power cost per kWh using various sizes of wind turbines and PV panels for two sites in Oman and calculated energy costs for the two sites which are almost same for three different sizes of wind turbine. Mohamed and Khatib [48] proposed an optimization method based on iterative simulation of a hybrid PV/wind/diesel energy and battery system for supplying a building load demand at minimum cost and maximum availability. The hybrid system is also simulated using HOMER but the proposed an optimization method which provides more accurate results as compared to HOMER results. Kusakana et al. [49] showed that a hybrid PV–micro-hydro system can meet the energy demand of an

isolated area in South Africa, successfully and then compared with other supply options such as grid extension and diesel generation.

Kenfack et al. [50] discussed sizing a micro hydro-PV-hybrid system for rural electrification in Cameroon with different combinations and discussed about various cost affects with different systems. Razak et al. [51] carried out the optimization and sensitivity analysis of proposed hybrid renewable energy system for the Pulau Perhentian Kecil, Terengganu, Malaysia based on sizing and operational strategy to obtain the optimal configuration of hybrid renewable energy based on different combinations of generating system. Güler et al. [52] proposed four different scenarios of a hybrid system for meeting a Turkish hotel's electrical energy demand where for insufficient renewable energy resources electrical energy is purchased from grid and for extra generation electricity is sold to the grid.

Baniasad et al. [53] presented techno-economic analysis for stand-alone applications between the hybrid (PV/wind/diesel/bat) systems and the hybrid (PV/wind/fuel cell) system with a yearly load of 24.4 MWh in Kerman having a total area of 500 m^2 at different fuel price scenarios. The comparison between hybrid (PV/wind/fuel cell) hybrid (PV/wind/diesel) systems show that even at high fuel price, the hybrid (PV/wind/diesel) system is economically better than the hybrid (PV/wind/fuel cell) system.

A feasibility study of photovoltaic wind, biomass and battery storage based hybrid renewable energy system for a residential area in Australia by Liu et al. [54] shows that Net Present Cost (NPC), Cost Of Energy(COE) and emissions of the system are lower than a diesel based system. Ashourian et al. [55] proposed an eco-friendly, economical, highly sustainable and reliable green energy systems for electricity generation of island resorts in Malaysia with a combination of solar and wind energy as intermittent renewable energy sources with a fuel cell and a battery storage energy system as a back up and compared the optimal configuration green energy system with a diesel-based energy system in terms of net present cost, sensitivity analysis and pollutant gas emission.

3.2. Other software based studies

Apart from large number of HOMER based research studies, only few research studies have been reported in the literature using other simulation softwares. The studies carried out using HOGA, Hybrid2, ARIES, TRNSYS and RETScreen, are presented in this section.

Castañeda et al. [56] presented a comparative study of sizing methods for a stand-alone PV–wind-storage hybrid system using Simulink design optimization, HOMER and HOGA. Hybrid system designed by first method gives the most economic hybrid system where as the second one, total system cost is highest with a minimum capacity hydrogen tank. Third method gave similar results as per first method with slightly higher expense, whereas the fourth method presents smallest hydrogen tank capacity. Rajkumar et al. [57] used Adaptive Neuro-Fuzzy Inference System [ANFIS] to model a solar–wind–battery hybrid standalone system and compared the results with HOMER and HOGA using real meteorological data for two locations Miri and Kuching in east Malaysia. It is found that ANFIS gives similar results as HOMER whereas HOGA predicts lower battery and PV size with large wind turbine component than HOMER & ANFIS.

Morgan et al. [25] discussed about ARES-I and ARES-II model for hybrid energy simulation program which deals with battery state of voltage (SoV).The system autonomy and effect of different battery temperatures can be estimated by ARES-II model which is after modified and enhanced version of ARES-I. The authors calculated the mean bias difference between ARES-I and ARES-II as 0.0022 and a root mean square difference of only 0.0028. In case of simulation run time ARES-II takes a few seconds longer to execute than ARES-I.

López et al. [58] applied Strength Pareto Evolutionary Algorithm (SPEA) to the multi-objective optimization of a standalone PV–wind–diesel (or gasoline) hybrid system with battery storage to minimize levelized cost of energy (LCOE) and the equivalent CO_2 life cycle emissions (LCE). The authors have developed HOGA as design tool and used for optimization of hybrid systems located in two different locations Zaragoza and jaca in Spain with different load profiles.

Andrew Mills and Al-Hallaj [59] designed and simulated 6.5 kWp solar array,12 kW wind turbine,2 kW fuel cell, 8 kW electrolyzer, and 3 kW hydrogen gas compressor hybrid system using Hybrid2 software to meet the varying 1 kW load needs in Chicago, USA. The study signifies the use of fuel cell as storage device to reduce battery bank and reduction in the size of renewable energy generators.

Kalogirou [60] has modeled a photovoltaic–thermal (PV/T) battery hybrid system for climatic conditions of Nicosia, Cyprus using TRNSYS. The TRNSYS is used to study the hourly, daily, and monthly performance of the system and for optimization of the water flow rate. In the study the electrical efficiency of system along with life cycle analysis have been carried out. The mean annual efficiency of a standard solar photovoltaic system is found to increase from 2.8% to 7.7% for a solar PV thermal hybrid system. The solar contribution of the system is found to be 49% with respect to thermal energy. The payback of this system is found to be 4.6 years. Thus, TRNSYS can be used for the analysis of thermal based hybrid system effectively. Rockendorf et al. [61] constructed thermoelectric generator–solar thermal collector system and photovoltaic–solar thermal collector hybrid systems. The simulation of both systems using TRNSYS 14.1 is carried out. The results shows that PV thermal hybrid system is a promising technology, as the electric output of PV-hybrid collector, is found to be higher than the thermoelectric collector.

RETScreen is also used for hybrid energy systems, but this software is more widely used in single source based renewable power system financial studies. Liqun and Chunxia [62] proposed a remote off-grid PV–wind–battery-hybrid system for Dongwangsha, Shanghai and carried out feasibility analysis including GHG emission, financial viability, and risk analysis using RETScreen. Optimized system is expected to generate 82.1% electricity by wind turbines and 16.2% from solar PV.

Some of the studies for different locations using these softwares are summarized in Table 4

The research studies indicate that HOMER is widely used tool for fast analysis in identifying optimum combination of hybrid systems based on the renewable resource availability at a particular location.

4. Case studies

A number of research studies using available hybrid softwares are described in Section 3. However, to illustrate further two studies are carried out for a solar PV–battery system and Solar PV–wind–battery system using two freely downloadable softwares RETScreen and HOMER.

4.1. Meteorological resource

For study purpose, a location is identified in western Himalayan terrain, Shimla (latitude 31.1°N and longitude 77.2°E) at 2650 m above sea level. Meteorological data base of RETScreen software is used for simulation in HOMER software also. On the basis of the project location and local meteorological data, the scaled annual

Table 4
Summary of important hybrid system research studies using various software tools.

Software used	Hybrid system studied	Location	Type of analysis	Highlights	Ref
HOMER	Biomass–solar PV–pico-hydel system	Kakkavayal, Kerala, India	Feasibility study and cost analysis	• Carried out system sizing and optimization. • COE of proposed hybrid system found economical than diesel based hybrid system	[37]
HOMER	Wind–diesel system	Algeria	Techno-economic assessment	• Evaluated energy production, life-cycle costs, greenhouse gas emission reduction • wind–diesel hybrid system found feasible at a wind speed of 5.48 m/s or more with fuel price of 0.162 $/l or more • 40% pollutant reduction found in wind–diesel hybrid system in comparison to diesel system	[43]
HOGA	PV–wind–diesel–battery storage system	Zaragoza and Jaca, Spain	Levelized Cost of Energy (LCOE) and the equivalent CO_2 life cycle emissions (LCE)	• Optimization of hybrid systems in different locations with different load profiles has been done • photovoltaics has been found as the essential component for hybrid systems in Spain	[58]
HYBRID2	Solar–Wind–Fuel Cell–Electrolyzer–Hydrogen system	Chicago, USA	Design and simulation	• Hybrid2 is used to predict long-term performance using site-specific resource data • The results indicate that renewable energy resource of the site is sufficient to meet the load requirements and the fuel cell integration may not be needed for such locations	[59]
TRNSYS	Photovoltaic–thermal (PV/T) hybrid system	Nicosia, Cyprus	Modeling and simulation	• PV/T hybrid system is found to produce more electrical energy than PV system for applications • Reduction in initial and running costs make PV/T hybrid system economically viable	[60]
RETScreen	Wind–PV–battery-fuel generator system	Shanghai, China	GHG emissions, costs, financial viability and risk analysis	• Feasibility analysis of n off grid wind–PV–battery system is carried out • Electricity generation contribution in the proposed hybrid system by wind turbines and PV are found to be 82.1% and 16.2%, respectively • Annual green house gas emission reduction is predicted	[62]

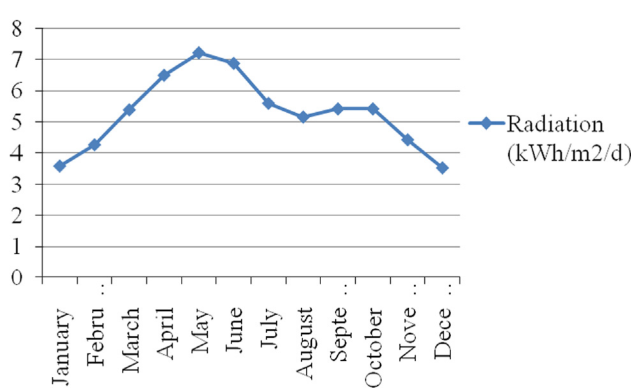


Fig. 6. Solar radiation profile.

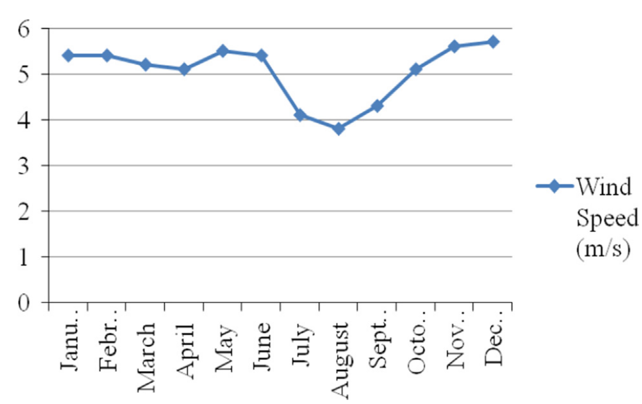


Fig. 7. Wind speed profile.

average value of solar radiation is 5.28 kWh/m^2/day. Maximum and minimum monthly average solar radiation values are observed during May and December with 7.21 kWh/m^2/day and 3.520 kWh/m^2/day respectively. The scaled annual average value of wind speed for the location is 5.05 m/s. The highest value of monthly average wind speed is observed during the month of December with a maximum of 5.7 m/s and the lowest value is observed during August with 3.8 m/s monthly average wind speed. The scaled annual average value of ambient temperature is 8.68 °C. The highest value of temperature is observed during the month of June with a maximum of 18.8 °C and minimum in the month of December with −0.2 °C. Figs. 6–8 show solar radiation profile, wind speed profile and ambient temperature profile respectively.

4.2. Load demand

A small residential load of annual average of 3.4 kWh/day and peak load of 0.489 kW are taken in both the studies. Monthly average load demand is shown in Fig. 9.

It is assumed that, the residential load can be delivered by PV–battery system and PV–wind–battery system also.

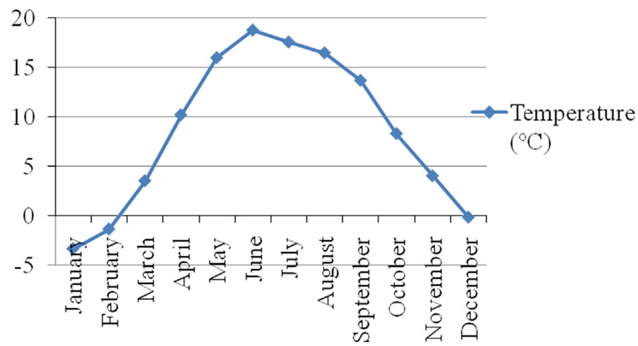


Fig. 8. Temperature profile.

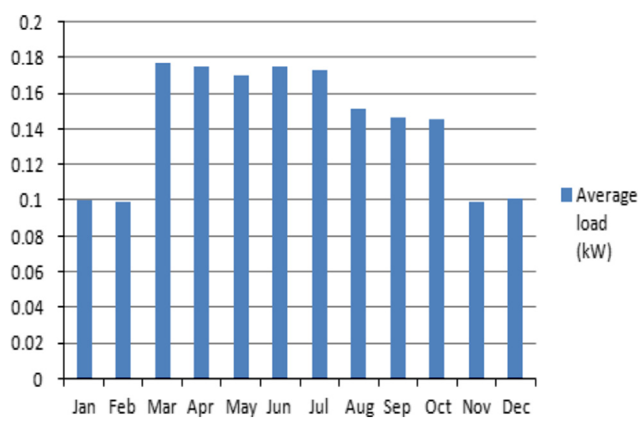


Fig. 9. Monthly average residential load.

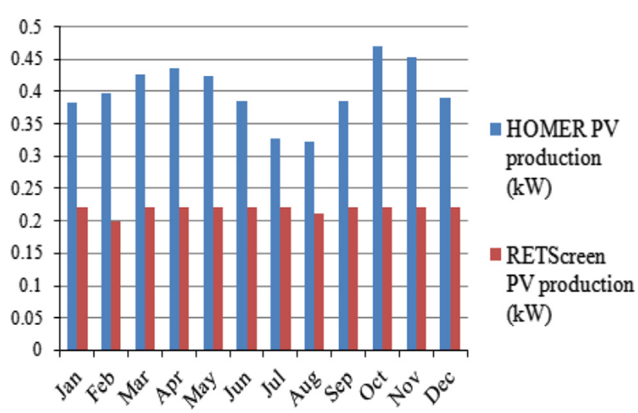


Fig. 10. Monthly PV production estimation by HOMER and RETScreen.

4.3. Case study I: PV-battery system

A comparison of HOMER and RETScreen simulation is made in this study. The results using HOMER and RETScreen software are shown in Fig. 10 with same meteorological data and other physical values. HOMER shows PV production of 3504 kWh/year with an excess electricity generation of 1819 kWh/year, where as RETScreen shows 2600 kWh/year electricity delivered to load. Monthly PV production by HOMER and RETScreen is shown in Fig. 10. This study shows that no excess energy production in RETScreen simulation. HOMER shows more PV energy production than RETScreen.

4.3.1. Comparison of HOMER and RETScreen softwares

A comparison of two widely used softwares HOMER and RETScreen is shown in this section. HOMER and RETScreen have some similarities like both take only global irradiation as input, and synthesize the diffuse irradiation internally [63]. RETScreen uses Microsoft Excel to perform analysis based upon statistical monthly averages with lots of meteorological and geographical in-built information. RETScreen uses Evans electrical model with month-averaged ambient temperature and the PV panel material characteristics data to calculate power output, where as HOMER uses basic relation model. Main difference between HOMER and RETScreen is shown in Table 5.

Main strength of RETScreen is the detailed economical analysis and strong database whereas HOMER is better suited for more advanced user and can handle a much denser simulation which makes HOMER one of the most widely used hybrid system optimization tool.

4.4. Case study II: PV–wind–battery system

A 3.4 kWh/day residential load is simulated in HOMER with a PV–wind–battery hybrid system. Polycrystalline PV system of 1 kW, 1 kW wind turbine and 10 number of 12 V batteries with 1 kW inverter are used in simulation study. Power curve of 1 kW wind turbine is shown in Fig. 11. Also 0%, 5% and 10% capacity shortage is introduced as sensitivity parameters. Table 6 shows main input parameters used in this study apart from meteorological parameters.

The project lifetime is taken as 25 years, system fixed capital cost as $ 400, system fixed operation and maintenance cost is $ 5 and annual real interest rate is taken as 2.01%.

4.4.1. Analysis without sensitivity inputs

Optimized result for a PV–wind–battery hybrid system without any sensitivity parameters is presented in Fig. 12

The first optimized result shows that system comprised of 1 kW of PV panel, 1 kW wind turbine with 1 kW of converter and

Table 5
Difference between HOMER and RETSceen.

	HOMER	RETScreen
Data import	Time series data import option	No option for time series data
Financial evaluation	Detailed financial analysis like RETScreen cannot be done by HOMER. But it calculates Net Present Cost, Cost of Energy, Operating Cost and Initial Cost	Detailed analysis like cost analysis, financial analysis, risk analysis and emission analysis and it is the strength of this software
Temperature effect	Temperature effect on solar PV system is included	Temperature effect is not included
Excess electricity production	Calculate excess electricity generated	No option to calculate excess electricity generated
Capacity Shortage option	Maximum annual capacity shortage can be included	No option for capacity shortage
Performance evaluation capability	Hourly basis data handling capability	Evaluated performance based upon monthly averages
Data base	Much more way of data input although it has some database	It has its own database and less data input way
Graphical representation	More graphical representation options	Less graphical representation option
Computational time	HOMER shows the computational time taken to simulate a study	RETScreen do not show the computational time taken as it is excel based software.

10 batteries give minimum cost of energy $ 0.818. Second optimized result shows a system with only 2 kW of PV system and third optimized result shows a system with 4 kW wind turbine and maximum cost of energy $ 0.951.Results show that only PV system generates 3504 kWh/year electricity with 1881 kWh/year excess electricity, whereas only wind based system generates 3477 kWh/year of electricity with 2131 kWh/yr excess production. PV-wind hybrid system generates less amount of excess electricity 1143 kWh/year and PV and wind production of 1752 and 869 kWh/year respectively.

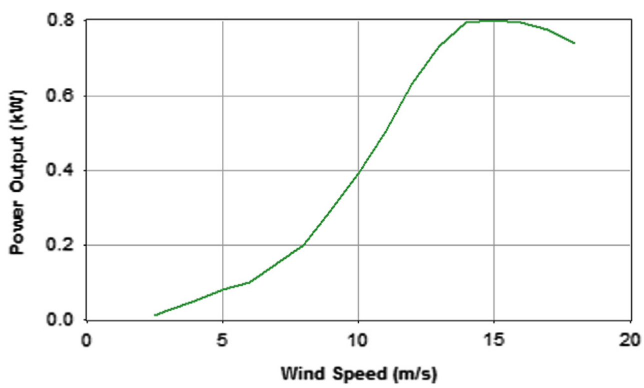


Fig. 11. Power curve of 1 kW wind turbine.

Table 6
Input parameters used for PV–wind–battery system.

Items	Cost ($)	Life time	Sizes to be considered	Other parameters
PV panel	Initial: 500 Replacement: 500 O & M: 0	25	0,1,2,3,4,5	Derating factor: 80% Ground reflectance: 20%
Battery	Initial: 800 Replacement:800 O & M: 0	–	0,1,2	Batteries per string: 10 Nominal capacity: 150 Ah Nominal voltage: 12
Inverter	Initial: 300 Replacement:300 O & M: 0	15	0,1,2,3,4,5	Efficiency: 90%
Wind turbine	Initial: 950 Replacement: 550 O & M: 9	20	0,1,2,3,4,5	Hub height: 30 m Rotor diameter: 1.75 m

This study also shows that PV–wind hybrid system runs with minimum cost of energy than PV only or wind only systems.

4.4.2. *Sensitivity analysis*

The same load is also simulated with using 0%, 5% and 10% of capacity shortage and the optimized result shown in Fig. 13.

First and second optimized results show the same configuration of 1 kW of PV panel, 1 kW wind turbine with 1 kW of inverter and 10 batteries with cost of energy $ 0.818 for the hybrid system with no capacity shortage. Third optimized result shows a hybrid system with 10% capacity shortage comprising of 1 kW of PV system, 5 kW wind turbine and 1 kW inverter with minimum cost of energy $ 0.336. In case of 0% and 5% capacity shortage system annual PV and wind production is 1752 kWh/year and 869 kWh/year respectively also an excess electricity generation of 1143 kWh/year. With a 10% capacity shortage, yearly PV and wind productions are 1752 kWh and 4347 kWh respectively.

4.4.3. *Computational time*

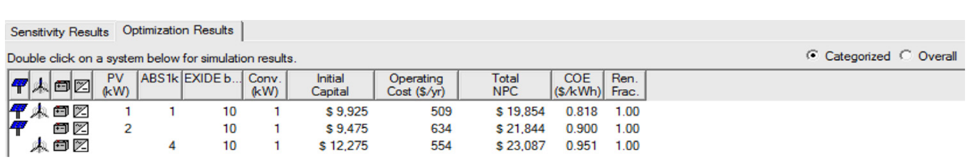
Without sensitivity analysis HOMER takes only 16 s to simulate the PV–wind battery system with all the necessary inputs. Simulation with 0%, 5% and 10% capacity shortage sensitive input takes 49 s. So this variation in time shows that computational time may vary according to size of inputs and sensitive parameters. More inputs and more complicated simulation need more time than a simple simulation study.

5. Conclusion

A review of 19 softwares tools used for multiple generator hybrid system analysis along with comparative analysis and research studies carried out using these tools, are presented in this study. Case studies of PV–battery and PV–wind–battery hybrid systems are presented to demonstrate the comparative capabilities of HOMER and RETScreen softwares.

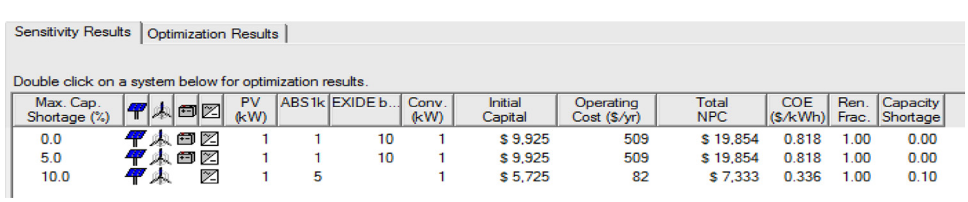
The conclusions are as follows:

- Among the nineteen software tools, HOMER is found to be most widely used tool as it has maximum combination of renewable energy systems and performs optimization and sensitivity analysis which makes it easier and faster to evaluate the many possible system configurations.
- The status of software tools HySim, HySys, SOMES, SOLSTOR, HYBRIDS, RAPSIM, ARES, IPSYS, and INSEL is not reported; so their present status is unknown. These softwares could be more useful for hybrid energy system research, if updates with some modifications like more renewable energy


Sensitivity Results | Optimization Results
Double click on a system below for simulation results. Categorized Overall

PV (kW)	ABS1k	EXIDE b...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
1	1	10	1	$ 9,925	509	$ 19,854	0.818	1.00
2		10	1	$ 9,475	634	$ 21,844	0.900	1.00
	4	10	1	$ 12,275	554	$ 23,087	0.951	1.00

Fig. 12. Optimized result of HOMER without sensitivity inputs.


Sensitivity Results | Optimization Results
Double click on a system below for optimization results.

Max. Cap. Shortage (%)	PV (kW)	ABS1k	EXIDE b...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
0.0	1	1	10	1	$ 9,925	509	$ 19,854	0.818	1.00	0.00
5.0	1	1	10	1	$ 9,925	509	$ 19,854	0.818	1.00	0.00
10.0	1	5		1	$ 5,725	82	$ 7,333	0.336	1.00	0.10

Fig. 13. Optimized result of HOMER with 0%, 5% and 10% of capacity shortage.

generator options and user flexibility are available in near future.

- Some improvements like incorporation of other energy sources, allowing user to modify or change control techniques with full flexibility, more user friendliness, needs to be done for these simulation tools which will be helpful in further research and hybrid system applications.
- The performance of software tools for hybrid energy system design can be improved through the implementation of various control methods, load demand management, economic planning, inclusion of various renewable and non renewable sources of energy with various storage systems, etc. which promises to reduce the total cost of the system with optimized planning.

The continuous up gradation of models and more user flexibility in the tools developed will be helpful for further research and stimulation of hybrid system application activities. Further follow up studies for demonstrating the capabilities of the simulation tools for hybrid system analysis can be taken up.

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